# Three-Dimensional Adjustment of Stratified Flow Over a Sloping Bottom

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## LONG-TERM GOALS

Our ultimate goal is to understand the dynamics of low-frequency ocean currents flowing over variable topography and the role of the bottom boundary layer in steering and modifying such currents.

## OBJECTIVES

Our immediate objective is to understand how advection of density within the bottom boundary layer influences the three-dimensional structure, evolution, and dynamics of both the bottom boundary layer and the overlying (interior) flow.

## APPROACH

Our study is based on the notion that the adjustment of stratified ocean currents flowing along sloping topography involves a feedback between the bottom boundary layer and the overlying current. The overlying current produces bottom stress that causes the bottom boundary layer to grow. The bottom boundary layer flow advects buoyancy across isobaths, creating vertical shears that reduce bottom stress and ultimately halt both the growth of the bottom boundary layer and the adjustment of the overlying flow. In some sense, the overlying current is 'controlled' by the bottom boundary layer.

Our approach consists of a combination of theoretical modeling, process-oriented numerical modeling and observational analyses. We are examining the deceleration of a finite-width stratified current over a sloping bottom, with and without vertical shear in the interior flow. We are analyzing existing observations for evidence of feedback between the bottom boundary layer and the overlying flow.

## WORK COMPLETED

We have completed a theoretical and numerical modeling study of the deceleration of a finite-width along-isobath current over a uniformly sloping bottom (Chapman, 2000) in order to understand the relative roles of frictional spindown and buoyancy shutdown (see below).

We revised and resubmitted a manuscript showing evidence, based on long-term, moored current observations from the west coast of the U.S., that near-bottom flow and hence the bottom stress is reduced due to adjustment of the near-bottom density field (Lentz and Trowbridge, 2000). This paper is now in press. In collaboration with John Trowbridge we have analyzed the Coastal Mixing and Optics observations to determine the dominant terms in the momentum balances within the bottom boundary layer and whether adjustment of the near-bottom density field is important to the dynamics.

**RESULTS**

The deceleration of a two-dimensional, finite-width current over a sloping bottom in a stratified fluid has been studied to quantify the relative importance of frictional spindown and buoyancy shutdown when both act simultaneously. Frictional spindown decelerates the current through Ekman suction and pumping at the current edges that transmit stresses into the interior fluid. Buoyancy shutdown is the process by which lateral advection of density in the bottom boundary layer generates thermal wind shears that reduce the bottom stress, thereby halting deceleration.

An analytical solution to a theoretical model of a downwelling current has been obtained. It suggests that buoyancy shutdown always reduces the deceleration time scale from that for frictional spindown alone and produces a non-zero steady along-isobath current overlying an arrested bottom mixed layer (Figure 1). The model is most sensitive to the Burger number $S=N\alpha/f$ where $N$ is the buoyancy frequency, $\alpha$ the bottom slope, and $f$ the Coriolis parameter. The steady state is reached more rapidly and the steady current is stronger with increasing $S$. Buoyancy shutdown remains important in the deceleration process even when its individual time scale for adjustment is an order of magnitude larger than the frictional spindown time scale.

A primitive-equation numerical model has been used to test the theory and its assumptions. Overall, the results are supportive of the theory, except that the theoretical model neglects the cross-isobath component of bottom stress and ignores vertical shears above the bottom mixed layer, the effect being to initially slow deceleration but then continue deceleration after the along-isobath stress has vanished. The result is a weaker steady flow in the numerical model, especially with stronger stratification. Interior vertical shears tend to decouple the near surface flow from the bottom mixed layer, producing more variable and sometimes stronger steady flows in the numerical model (Figure 2). Details of the flow in the bottom mixed layer are highly dependent on the choice of turbulence closure scheme.

Buoyancy shutdown is also important in the deceleration of upwelling currents, substantially reducing the time to reach steady state from that for frictional spindown alone. Details of both the deceleration and the steady state vary sharply with the turbulent closure scheme, so generalizations are difficult.

Direct covariance estimates of bottom stress over the New England shelf made by J. Trowbridge and S. Williams (WHOI) and the associated drag coefficient are about an order of magnitude smaller than typically assumed over continental shelves. The small bottom stresses are apparently due to the smooth, featureless bottom at this site resulting in a small bottom drag coefficient, rather than buoyancy adjustment within the bottom boundary layer. Comparisons with other terms in the depth-averaged momentum balance suggest bottom stress is negligible, e.g. bottom stress is nearly a factor of ten smaller than the wind stress. However, preliminary analysis of the bottom boundary layer dynamics indicate along-isobath bottom stress forces a weak cross-isobath transport, consistent with an Ekman balance. However, this stress-driven flow is only a small component of the near-bottom cross-isobath velocity structure.

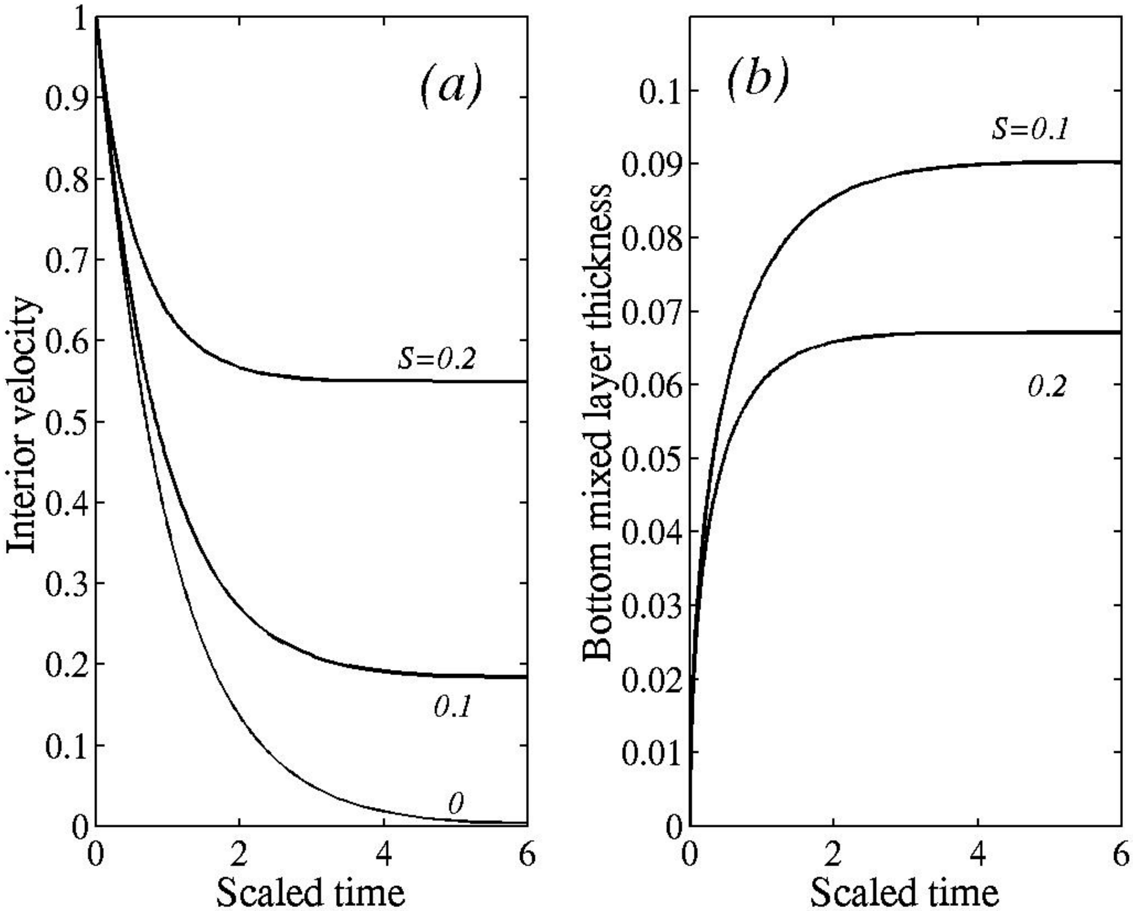


***Figure 1: Time evolution of the (a) interior velocity and (b) bottom mixed layer thickness from a theoretical model of a decelerating current (for several choices of Burger number S). The velocity has been scaled by the initial velocity, and the bottom mixed layer thickness has been scaled by the water depth. Time has been scaled by the frictional spindown time scale, h/r, where h is the water depth and r is the bottom friction coefficient.***

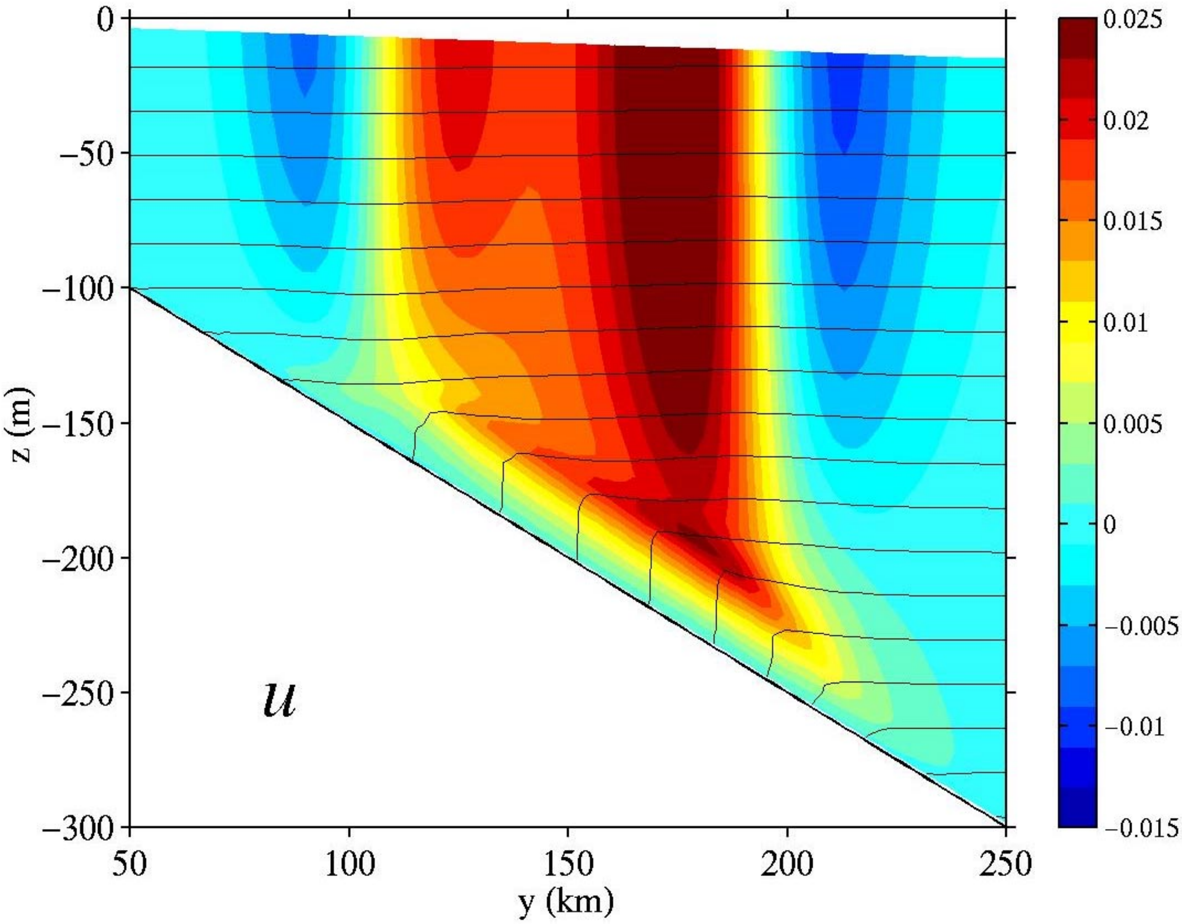


***Figure 2: Vertical section of along-isobath velocity (u) with density contours superimposed, after 20 days of deceleration in the numerical model. Velocities are given on the bar on the right in m/s. The initial velocity was 0.1 m/s.***

**IMPACT/APPLICATIONS**

Our modeling results suggest that buoyancy shutdown should influence currents over the continental shelf on time scales of one week and greater. This is consistent with observational evidence. In general, the results support the notion that the bottom boundary layer may play an important (and perhaps dominant) role in the behavior of ocean currents, even when the boundary layer is thin compared to the current depth. The Coastal Mixing and Optics measurements indicate there can be substantial spatial variations in the bottom drag coefficient over shelves. This implies that proper prescription of the bottom drag coefficient may be critical to accurate numerical simulation of shelf circulation.

**TRANSITIONS**

There are no transitions at this point.

## RELATED PROJECTS

We are working closely with Glen Gawarkiewicz who is leading a field program in the South China Sea, as part of the ONR-sponsored ASIAEX program. Many of the ideas and results from our modeling studies have applications in that region, so we are coordinating our modeling efforts with the developing field effort.

As noted above, we are collaborating with J. Trowbridge to examine the character of the bottom boundary layer and the interior flow during the CMO field program to determine whether the structure and dynamics are consistent with our idealized model.

## REFERENCES

Chapman, D.C., 2000. Deceleration of a finite-width, stratified current over a sloping bottom: frictional spindown or buoyancy shutdown?, J. Phys. Oceanogr., to be submitted.

Lentz, S.J., and J. Trowbridge, 2000. Fall and winter mean current profiles over the northern California shelf, J. Phys. Oceanogr., in press.

## PUBLICATIONS

Chapman, D.C., 2000. Deceleration of a finite-width, stratified current over a sloping bottom: frictional spindown or buoyancy shutdown?, J. Phys. Oceanogr., to be submitted.

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